THE ELECTRON PENCIL

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The principle of the cathode ray oscillograph was discovered by Braun 25 years ago and the tube has always been known by his name. In Braun's tube, however, the electrons were produced by a high voltage discharge, between the metal terminals through the remnants of gas left in the tube. Some of the electrons went through a tiny hole in the terminal plate and struck the end of the tube making a spot of light where the stream of light ended. If an electric voltage was applied between the plates the stream would be deflected toward the positive plate and the spot moved across the screen.

The Braun tube had two major limitations. The air left in it became gradually exhausted and had to be renewed, while the voltage required to operate it was from 10,000 to 50,000 volts direct current. The apparatus necessary to generate a current of this voltage and its maintenance was expensive and it was also dangerous for the operator to handle. In addition the tube was not stable. The electrical characteristics varied with the amount of gas in the tube and the electron stream was falsely deflected by negative charges collected on the glass walls of the tube. These charges collect on the walls of the tube because the pressure of the gas is not high enough to dispose of them. For these reasons the Braun tube was never used as much as it deserved when its advantages were considered.

The development of the vacuum tube, however, opened up a way to obtain the stream of electrons more easily by the use of the heated filament. In Fig. 1 *F* is the filament which is heated by a six volt battery as in the ordinary vacuum tube. Another battery built up of small radio "B" cells provides 300 volts between the filament and the other electrode *A*. This electrode is in the shape of a little tube. The voltage at which it is maintained draws off the little electrons from the filament. They pass through the hole in the plate *S* and down through this tube. From there they shoot on down between the plates P_1, P_2 to the end of the vacuum tube, where they strike the chemical coating of the screen, making a bright dot. To simplify matters only one pair of plates is shown in the diagram. The other pair is at right angles to the first and is used to swerve the beam at right angles to the motion produced by the first pair of plates. The plate P_2 has a lead which passes through the glass to a terminal and the other is connected to the tubular terminal *A* and from there to a terminal outside the tube. In this way when a voltage is put across the two plates the stream of negative electrons will be swerved toward the positive plate.

When it is desired to measure a current instead of a voltage, two small coils, L_1 and L_2, which consist of a few turns of wire, are placed on opposite sides of the tube. The magnetic effect of the current deflects the electron stream in a direction parallel to the plane of the coils and the luminous spot will be moved as before.

In the cathode ray oscillograph recently developed by Dr. J. B. Johnson the disadvantages of the Braun tube have been overcome. The adoption of the heated filament did away with the necessity of maintaining a high voltage between the filament and the other electrode. The elements were so designed that the electrical characteristics of the tube were maintained independent of the pressure of the gas in the tube. It was found in the development of this tube that when it was exhausted to a very high vacuum the individual electrons of the stream separated. This stream of electrons shooting out through the tubular electrode resembles very much a stream of water from a hose with which a small boy can draw designs on a board fence. The electrons separate, just as the globules of water do, making the stream wide where it strikes the end of the tube.

Of course the boy when making his figures on the fence doesn't care whether the pencil he is drawing with is an inch in diameter or a foot. However, when you are going to calculate the action of an electric current you must use a sharp pointed pencil. So a way had to be found to focus a stream of electrons down to a very fine point.

Consequently, a tube was constructed containing a small amount of argon, an inert gas. First the tube was exhausted of all the air possible even to baking the glass while it was being exhausted so as to release from the glass all the gas which could be freed by the heat generated during operation. Then the argon gas was introduced. Now argon is made up of monatomic molecules, each of which has a nucleus positively charged with electricity, and surrounded by two negatively charged electrons held to it by electric attraction. In the operation of the tube the free electrons shoot down the tube at a velocity of 6,000 miles per second and when one of them hits one of these molecules which is moving at the rate of only one-fourth of a mile per second, the force of the collision knocks off one or more electrons from the molecule. Formerly the positive charge of the nucleus was neutralized by its ring of negative electrons, but when some of the electrons are knocked off, the nuclues, now positive, begins to attract free negative electrons. As these nuclei are heavy as compared to the flying electrons, they are simply buffeted around by the latter and they stay in the line of the electron stream where they are formed. Therefore, there is along the whole length of the electron stream a line of positive nuclei which attract the free electrons and hold them in the straight and narrow path in spite of the repulsion between electrons which tempts them to spread out. Further, the dislodged electrons shooting off in all directions soon fill the space outside the stream with negative charges which repel the flying electrons keeping them in their own path. In addition the pressure of the gas in the tube is high enough to denude the glass walls of the tube of negative electric charges.

In order to prevent the bombardment of the filament by positive ions which destroy its oxide coating and thus render it inactive, the filament is sealed in the glass mounting tube, and to prevent the ions from striking the filoment when they come through the hole in the plate *S*, the filament is bent in a circle as shown in the photograph. The filament is made of ribbon instead of wire, which leaves just an edge exposed to these ions.

The great advantage of the cathode ray oscillograph lies in the fact that the stream of electrons forms a nearly weightless pointer whose movement will accurately follow the changing conditions in the circuit to which it is connected. By avoiding mechanical inertia, as it does, it is capable of recording frequencies up to millions of cycles per second.

This interesting strument can be used in many ways. When one set of deflector plates alone is used the electrical potential to be measured causes the luminous spot to become a bright line whose length is proportional to

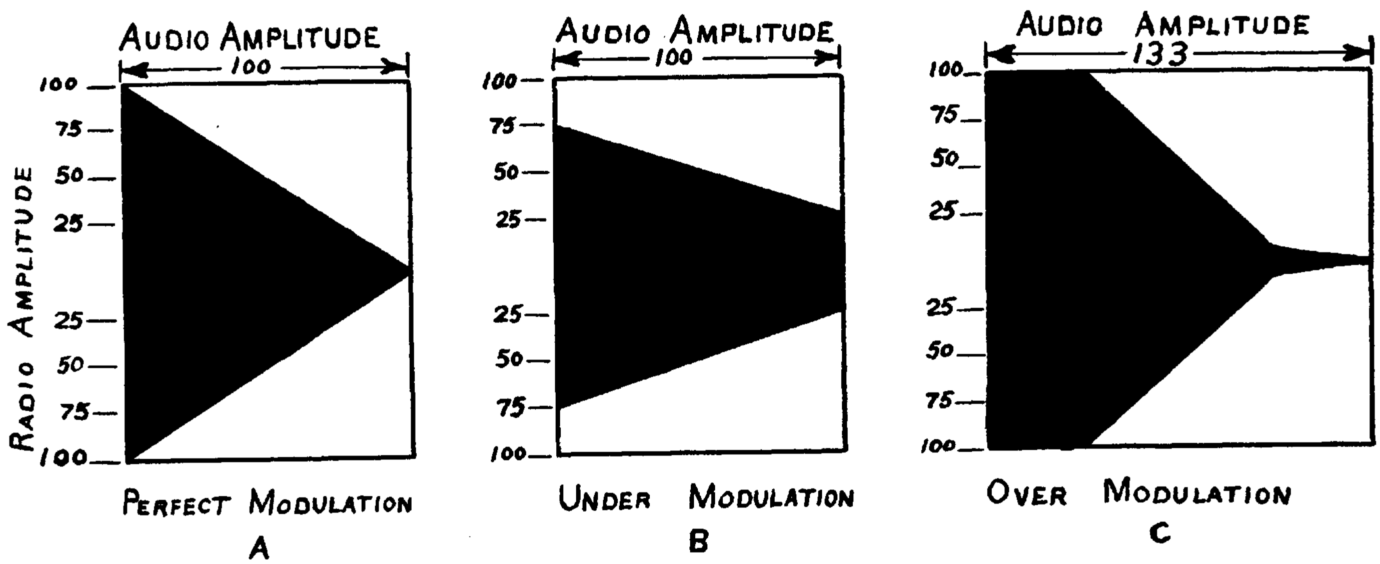

FIG. 2

the amplitude of the voltage wave. If now another voltage varying with time is applied to the other pair of plates the beam will be swept across the field and its wave-form can be seen. Thus, by talking into a telephone transmitter one can "see himself talk."

The familiar "hysteresis loop" can be shown most vividly with this oscillograph. The magnetizing current moves the spot "from side to side" and the resultant magnetism in the sample moves it "up and down." Such a set-up can be made by winding the magnetizing coil on a fibre tube, into which is slipped a thin strip of the material. The tube is so placed that the end of the sample comes up to the oscillographic tube where its magnetism can swerve the flying electrons.

By connecting each set of deflecting elements to alternating currents of different frequencies, the spot will trace out Liccajous figures. If the frequencies are steady and one is an exact multiple of the other the pattern will be stationary, otherwise it will change as the phase relation of the current changes. For two currents differing widely in frequency, the pattern may be too long for its ends to appear on the coated end of the tube, but the fact that it is steady shows that one frequency is an exact multiple of another. Thus the carrier wave of a broadcasting station may be amplified and impressed on one set of deflector plates, while a locally generated frequency impressed on the other set of plates is adjusted to a match with it. The local wave is then matched with another local frequency at say, 1/100 of its frequency and this in turn is "stepped down" to a frequency which can be measured easily.

In radio broadcasting it is important that the voice frequency voltage which modulates the radio frequency output shall be large enough to fully load the transmitter, yet not large enough to overload it. Direct evidence of this is given by connecting the cathode ray oscillograph in such a way that while the radio output moves the spot up and down the audio input moves it sideways. According to the theory of modulation, the radio current should vary uniformly from zero to a maximum as the voice voltage moves from one extreme of its cycle to the other. Figue 2-A shows this condition, or 100% modulation, Figure 2-B shows a lower amount; corresponding to a softer passage in the music. Figue 2-C shows over-modulation, which happens when some ambitious operator "crowds" this transmitter in a try for some new distance record. Over-modulation means distortion and dissatisfaction from his regular near-by audience.

The chief value of this cathode ray oscillograph is to get quick visible indications of what is going on in an electric circuit. It can therefore be used to explore a

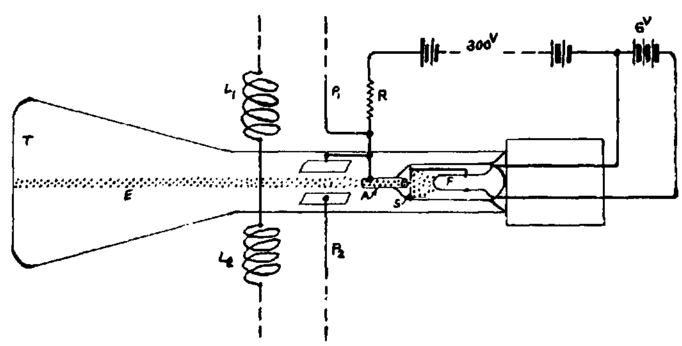

FIG. 1

situation and ascertain roughly what is going on as a first step to devising measurements which will be more accurate. For example, after the apparatus is set up hysteresis loops can be taken very rapidly on one sample after another as against a half day each by the more accurate "point-by-point" method..

Used in radio broadcasting work the cathode ray oscillograph provides a means of constantly observing the degree of modulation obtained. Whether used in the laboratory, the radio station, or the class room, the new electron pencil will prove a valuable tool for practical scientific workers.